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(54) Title: LASER OPTICS INTEGRATED CONTROL SYSTEM AND METHOD OF OPERATION

Integrated Laser
Communications Control
System

(57) Abstract: A controller (320) for controlling various operational parameters of the Laser Module (303). The modulation drive signal (300) causes the circuits in the driver (301) to send a signal to the output (302) so that the laser can send an optical power output (304) proportional to the drive signal (300). The control methods in Laser Controller IC (320) consist of control algorithms embedded in firmware. The Laser Controller IC (320) includes support circuits for control of a laser. Some of the distinguishing features in the present invention are 1) feedback information from the sensors is obtained in a synchronous manner as a snapshot of the laser performance, and 2) algorithms handle the entire set of controls in firmware. The algorithm feature allows for advanced servo controls, which precisely stabilize the laser, can accommodate adaptive controls, and can be leveraged from one laser transmitter design to another.

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

LASER OPTICS INTEGRATED CONTROL SYSTEM AND METHOD OF OPERATION

CROSS REFERENCES TO RELATED APPLICATIONS

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This is a continuation in part of application Ser No. 09/724,692
Filed on November 28, 2000, entitled "Electro-Optic System Controller and Method
of Operation", which in turn is a continuation in part of application Ser No.
09/472,709 filed on December 24, 1999, entitled "Electro-Optic Interface System and
10   Method of Operation", now patent US 6,446,867 B1, which in turn is a continuation
in part of patent "Isolation Instrument for Electrical Testing", U.S. Pat. No.
6,028,423, filed on December 11, 1997. This utility application is also filed based on
provisional application 60/344,177 filed December 27, 2001, entitled "Integrated
Communications Controller and Method of Operation".

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BACKGROUND

The invention relates to a Laser Feedback Control System. The control system utilizes
algorithms of modern digital controls and utilizes a laser controller Integrated Circuit.
20   Use of edge emitter lasers for high performance long haul and metropolitan networks
will continue in high performance applications including wavelength division
multiplexing. VCSEL arrays have been used increasingly in fiber optics
telecommunication due to their low cost. Widespread use will place increasing
demands on performance of all elements of the electrical to optical interface.
25   Increasing speed of computers will place increased demands on the performance of
transmitters using VCSELs. All network applications are a fast growing market.
The market is demanding low cost and short development time with an increased
level of reliability and intelligence in the transmission systems.

30   Prior art has attempted various methods to control lasers. Levinson, in United States
Patent 5,019,769, dated May 28, 1991, described a semiconductor laser diode
controller and laser diode biasing control method. Although a programmed
microcontroller is disclosed, a limitation to Levinson is the teaching is to only
"...accurately controlling the process of turning on and selecting the operating point of
35   the laser diode." More specifically, Levinson is directed "...preventing light from
the laser diode's from accidentally damaging user's eyes." Levinson does not appear
to disclose an integrated circuit solution. The micro controller is used in a hardware
adjustment mechanism rather than for servo computations. Levinson teaches away
from the present invention. On the other hand, in the present invention, algorithms
40   handle the entire set of controls in firmware and do not rely on analog closed loop
controls. This feature allows for advanced controls, which precisely stabilize the
laser, can accommodate adaptive controls and can be leveraged from one laser
transmitter design to another.

45   King, et al. In United States Patent 5,812,572, dated September 22, 1998,
discloses intelligent fiberoptic transmitters and methods of operating and
manufacturing the same. Intelligent fiberoptic/laser diode transmitter/controller
modules and methods of operating and manufacturing the same are disclosed.

"During calibration procedures for the modules, a laser diode is characterized over a defined operating temperature range." ... "During operation, an embedded microcontroller together with analog to digital converters, digital to analog converters and other associated circuitry, dynamically control the operational parameters (e.g. modulation and bias current) based on the current operating conditions (temperature, power supply)." A limitation of King, et al is the limited scope of the disclosure. King, et al appears to teach away from an integrated circuit solution. More specifically, a micro controller is used in a hardware adjustment mechanism rather than for servo computations. In addition, King, et al discloses characterizing of a laser diode. On the other hand, the present invention uses algorithms to handle the entire set of controls in firmware and does not rely on analog closed loop controls. This feature allows for advanced controls, which precisely stabilize the laser, can accommodate adaptive controls and can be leveraged from one laser transmitter design to another. The present invention also discloses an operating system, advanced servo control methods, and adaptive, reconfigurable controls in an integrated control system.

Still another patent in prior art is Sanchez, in U.S. Pat. No. 6,494,370, dated December 17, 2002. Sanchez is the inventor of the present invention as well. However, U.S. Pat. 6,494,370, is an electro-optic system controller and method of operation disclosing a method for calibrating a laser module system. This disclosure is more limited in scope than the present invention because it focuses on some hardware aspects of controls.

Other prior art is discussed below.
• Some control systems as shown in **FIG** 1, utilize analog controllers. Adjustment of laser power with changes in temperature is done by a temperature sensitive device, which adds compensation current to the laser drive. This approach is made with fixed controls that need to be hardwired for each application. Because of that reason this implementation reduces the possibilities for modifications and the possibilities for leveraging from one product generation to another.
• Other methods are utilized for controlling the more complex applications of wavelength division multiplexing WDM have utilized some elements of closed loop control but generally only for stabilizing the wavelength of the laser with a wavelength locker.
• Other approaches consist of open loop drivers with costly characterization of the laser/VCSEL array.
• An example of a more elaborate control system is shown in FIG 2. The system accommodates for an initial characterization of the laser at all temperatures. In this control system, a photodiode-monitoring laser output power is used as feedback. The photodiode characteristic is digitally adjusted at the factory with a D/A converter and a microprocessor. This adjustment is in lieu of a mechanical potentiometer and it is used for an initial adjustment of the photodiode and to compensate for deficiencies of the photodiode with temperature. It is significant that in Figure 2, the control loop is still an analog control loop. The difference between the loop in Figure 2 and a digital control loop is that in a digital control loop, the magnitude of the laser drive signal is determined in a digital process. For example, the photodiode signal is first digitized, the processor then utilizes calibration and adjustment algorithms to determine what

the drive signal magnitude should be, and finally, a D/A converter is used to control the driver so it produces the correct magnitude of the drive current. In contrast, in a digital control system, the signals are immediately digitized, all of the signal processing for a servo system is carried out in the controller firmware and then the excitation/control of the laser is done with the D/A converters controlling the driver. This allows for complex signal processing to be done in the firmware.

- The analog circuits utilize complex analog topologies, which are difficult to leverage, support and calibrate. The analog parts also require a significant effort in maintaining component quality in production.
- Other deficiencies of analog control systems are in the way the control algorithms are implemented. Adjustments are made for power control but utilize very basic methods of control because a significant set of the decisions and calculations are done with analog components. For example, the laser power control is done with a system that makes adjustments based on deviations from a set point with a resulting in on-off adjustments rather than a servo system.
- Prior solutions do not effectively leverage solutions from one product to another because they are based on fixed hardwired design implementations of a control system.
- Prior solutions rely on a multiplicity of integrated circuits and components that are chosen every time the laser system is designed. This situation causes a larger set of packages to be utilized increasing costs and decreasing reliability.
- Another issue of the known prior art methods is that complex issues need to be decided very early in the projects. With rigid hardwired implementations (rather than programmable which can be implemented late in the project) the options are reduced thus increasing risk.

SUMMARY OF THE INVENTION

In reference to Figure 3, the control system (200) consists of an apparatus containing a digital controller IC (320), a driver (301), a set of sensors (306,307,309,319) and digital control methods embedded in controller IC (320). The control system contains the necessary features to control the various operational parameters of the Laser Module (303).

The control first starts with a modulation drive signal (300); the drive signal causes the circuits in the driver (301) to send an appropriate signal to the output (302) so that the laser can send an optical power output (304) proportional to the input signal (300). The Laser Module (303) may contain a semiconductor laser or a VCSEL laser array and also may contain the necessary features to tune the laser wavelength. The control methods embedded in Laser Controller IC (320) consist of control algorithms embedded in firmware. The Laser Controller IC (320) includes the necessary support circuits for control of a laser. The circuits in the controller may include among other circuits digital functions such as a processor, ROM, RAM, non volatile RAM, clock, reset, I/O. Mixed analog and digital features include one or more digital to analog converters, potentiometer, sample and hold amplifiers, analog multiplexer, programmable gain amplifier analog multiplexer, programmable gain amplifier, analog to digital converter, operational amplifiers. Power control circuits include a

laser power control latch, a laser power switch and a laser overvoltage and transient control protection circuit. Other possible circuits may include optical link characterization support circuits such as a precision voltage reference and a reference drive switch for analog signal support and a set of Optical Link Characterization circuits, which provide support for such as bit error rate determination.

The control system architecture can control one or more lasers or a VCSEL array by a change in the type of driver. Some of the distinguishing features of the control system in the present invention from the prior art are:

Feedback information from the sensors is obtained in a synchronous manner as a "snapshot" of the laser performance utilizing either Sample/Hold devices or by very rapid sampling of the feedback information.

Algorithms handle the entire set of controls in firmware and do not rely on analog closed loop controls. This feature allows for advanced controls, which precisely stabilize the laser, can accommodate adaptive controls and can be leveraged from one laser transmitter design to another.

- A novel feature of the invention is that the apparatus will interface with the set of sensors typically needed to determine the state of the laser system under control. These sensors may include a temperature sensor, power sensor, and current sensor or wavelength sensor.
- Another novel feature of the present invention is that the control processes implemented in the algorithms define the "plant characterization". This information fully characterizes the laser and sensors. Preferably, the characterization is carried out only during product development rather than during production test. The characterization allows for a precise real-time control of the laser.
- A third novel feature of the invention is a set of advanced digital control algorithms. The algorithms sample the feedback variables, perform the necessary computations to carry out a real-time response and then set the output variables needed to simultaneously operate on the laser system in order to maintain the set point for the optical signal output. This closed loop control is done for all of the output variables with a servo control approach.
- Still another unique feature of the invention is it is a Universal Control System in that it can adapt the control to different lasers or VCSEL arrays. The control system requires a change in firmware parameters in order to adapt to the different type of laser
- Yet another unique feature of the present invention is that a complete set of specialized features needed for laser feedback control systems are incorporated into one integrated circuit, which substantially increases reliability and reduces cost of the laser transmitter.
- Finally, other novel features of this invention are in the Methods of Operation. These methods include a real time operating system for a laser transceiver. The operating system allows for a structured approach that offers significant leveraging of the firmware resources by the different programs that are embedded in the controller. In addition, the operating system facilitates interconnection and compatibility of firmware programs written by different programmers in a standardized manner, which promotes leveraging of programs from one product generation to another and also allows programs from various vendors to connect to each other in an orderly fashion.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG 1 illustrates a typical analog control system from prior art.
5   FIG 2 illustrates a mixed analog/digital control system from prior art.
FIG 3 illustrates a block diagram of the control system of the present invention.
FIG 4 illustrates a block diagram of the Integrated Laser Communications Controller
(320) of the present invention.
FIG 5 illustrates the methods of operation, comprising a real-time operating system.
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DESCRIPTION OF THE PREFERRED EMBODIMENTS

Apparatus
15   FIG 1 illustrates a typical analog control system from prior art. This control
system utilizes analog controllers. Adjustment of laser power with changes in
temperature is done by a temperature sensitive device, which adds compensation
current to the laser drive. This approach is made with fixed controls that need to be
hardwired for each application. Because of that reason this implementation reduces
20   the possibilities for modifications and the possibilities for leveraging from one
product generation to another.

FIG 2 illustrates a mixed analog/digital control system from prior art. This
system is an example of a more elaborate control system. The system accommodates
25   an initial characterization of the laser at all temperatures. In this control system, a
photodiode-monitoring laser output power is used as feedback. It is significant that in
FIG 2, the control loop is still an analog control loop. The difference between the
loop in FIG 2 and a digital control loop, as in the present invention, the magnitude of
the laser drive signal is determined in a digital process. In a digital control system,
30   the signals are immediately digitized, all of the signal processing is carried out in the
controller firmware and then the excitation/control of the laser is done with the D/A
converters controlling the driver. This allows for complex signal processing to be
done in the firmware.

35   FIG 3 illustrates a block diagram of the control system of the present
invention. FIG 3 contains the architecture of the Integrated Laser Communications
Control System (200). The Control System (200) consists of a Driver (301), a Laser
Controller IC (320), a set of Sensors (306, 307, 309, 319) and control algorithms that
are embedded in the Laser Controller IC (320). The control system is used to provide
40   all of the necessary functions required to operate properly the Laser Module (303) in
order to produce the required Laser Light Output (304). The Driver (301) takes as
inputs Drive Signal (300), Modulation Signal Control (310), and Bias Signal Control
(311). The Driver (301) then produces Laser Voltage and Current Sense Signals
(319). The Driver (301) also produces Modulation Current (302) and Bias Current
45   (314). The Laser Module (303) utilizes Modulation Current (302) and Bias Current
(314) to produce the Required Light Output (304).
The feedback Sensor information consists of a variety of Laser Performance
Parameters: A portion of the Light Output from the Laser Module (303) is sent

through an Optical Path (308) to the Photodiode Sensor (309) in order to determine
Laser Power Output. In some cases additional Photodiode Sensors are utilized to
determine the Laser performance for applications such as Wavelength Division
Multiplexing. A portion of the Laser Light Output (304) may be sensed at 305 and
5   coupled to the Wavelength Locker (306) in order to determine the Wavelength of the
Light Output (304). A Temperature Sensor (307) is utilized to determine the
temperature of the Laser Module (303). The Laser Voltage and Current Sense Circuits
(319) are utilized to provide feedback information on the various currents and
voltages that are applied to the laser. The Drive Signal Feedback (300) sends
10   Feedback (318) to the Laser Controller IC (320) in order to provide real time
information of the magnitude of the Drive Signal (300).
The Laser Controller IC (320) may utilize as inputs one or more of the following:
Laser Voltage and Current Sense (312), Photodiode Sensor(s) Output (315).
Temperature Sensor Output (316), Wavelength Locker Output (317) and Input Drive
15   Signal (318). Which Sensors are utilized by the controller is dependent on the type of
Laser that is being controlled. The Laser Controller IC (320) first digitizes the sensor
information. Afterwards, the Control System Algorithms, which are embedded in the
Laser Controller IC (320), will determine what are the appropriate feedback controls
to be applied to the Driver (301) and the Laser Module (303). The Laser Controller IC
20   (320) produces Modulation Control (310) that is applied to the Driver (301) and
controls the magnitude of the Modulation Current (302) that is applied to the Laser
Module (303). The Laser Controller IC (320) produces Bias Current Control (311)
that is applied to the Driver (301) and controls the magnitude of the Bias Current
(314) that is applied to the Laser Module (303). For Wavelength Division
25   Multiplexing Systems, the Laser Controller IC (320) also provides one or more Laser
Wavelength Tuning Outputs (313). The Wavelength Tuning Outputs (313) are
utilized by the Laser Module (303) to modify the Wavelength of the Light Output
(304).
FIG 4 illustrates a block diagram of the Integrated Laser Communications Controller
30   (320) of the present invention. FIG 4 shows the architecture for the Integrated Laser
Communications Controller (320). The Communications Controller is implemented in
an Integrated Circuit and contains all of the support circuitry required by the
Feedback Control System to Control with precision a laser. The Integrated Circuit
contains mixed signal circuits, which include digital and analog circuit, which may be
35   manufactured in various available technologies such as Complementary Mosfet
Technology. The Integrated Circuit also hosts the embedded firmware, which
contains the Control System Algorithms. Not all of the circuits may be required for a
given control system. How the circuits are utilized is dependent on the laser
application used.
40   The digital portion of the Laser ControllerIC (320) consists of a Microprocessor
(401), which carries out the arithmetic, logical and program execution operations. The
memory related circuits consist of a Read Only Memory (ROM) (402) which stores
the embedded firmware. RAM (403), non-Volatile RAM (404) utilized to store
additional information during run time. The additional information may consist of
45   parameters that adapt the Laser Control System (200) to a specific laser. The
memory related circuits are connected with Bus (480) to the Microprocessor (401).
The Bus (480) also is available to the outside of the Integrated Laser Communications

Controller as an External Memory Interface (437). This interface is used for
additional external ROM or other fast storage or functional circuits used to extend the
capability of the Laser Communications Controller (320). Other digital functions
consist of a Reset Generator (405) that generates a reset pulse during power up. The
5   Reset Generator is connected to the Microprocessor (401) with the Reset Line (481).
The Reset Generator also can drive external circuits with a Reset Output (438). The
Microprocessor (401) utilized a Clock Input Line (482), which is sent by the Clock
Generator (406). The Laser Controller IC can also utilize an external clock by means
of the Differential Lines (439,440). Additional functions are provides by a set of
10   Timers (407), General Purpose Digital I/Os (408). The Laser Communications
Controller (320) may preferably contain 8 or more Digital I/Os (408), which are
available for external functions through pins at (441-442). External communications
to a host computer is made using a Serial I/O (409). The Serial I/O (409) may be an
RS 232 type or an USB type of communications interface. The Serial I/O (409) is
15   available through pins at (443,444). The Microprocessor (401) utilizes internal Bus
(483) to connect to the Timers (407), Digital I/Os (408) and Serial I/O (409). Internal
Bus (483) may also connect to a Parallel I/O (410), which connects to a host computer
through pins (445-446).

        The mixed signal portion of the Laser Controller Integrated Circuit starts with
20   Sensor Inputs (447-448). These inputs connect to a set of Operational Amplifiers
(415). The Amplifiers (415) are of high performance and are utilized to carry out
conversion of monitoring Photodiode Current to a voltage with a high degree of
precision and linearity. Other uses for the Amplifiers is to sense that Drive Signal
(300) so that the Control System can obtain real time information of the magnitude of
25   the Drive Signal (300). For some digital systems it is possible to receive the input
signal at (492), into a Signal Detector (493), which connects to the Internal Bus (483).
The Signal Detector (493) assists the Microprocessor (401) in determining an integral
of the Modulation Current in order to perform any needed adjustments to the laser
drive. The outputs (485-486) of the Operational Amplifiers (415) are connected to a
30   set of Sample Hold Amplifiers (414). The function of the Sample Hold Amplifiers
(414) is to obtain a snap shot in time of all of the feedback information that comes
from all of the Sensor Inputs (439-450). The sensor feedback information is
synchronized and provides the control system with the necessary means to implement
a Servo System Control of the laser parameters. This feature is an important
35   improvement of this invention in that the laser parameters are maintained with a real
time Servo control as opposed to an on and off control system algorithm. The Sample
Hold Amplifiers (414) send Outputs (487-488) to the Analog Multiplexer (413). The
Output of the Multiplexer (489) sends the output to the input of the Programmable
Gain Amplifier (413a). The Programmable Gain Amplifier (413a) is controlled by the
40   Microprocessor (401) through Control Line (484) and is capable of adapting for
different levels of feedback information from Sensor Feedback Inputs (449-450). The
Programmable Gain Amplifier (411) is connected through (490) to the Analog to
Digital Converter (411). The Analog to Digital Converter contains the appropriate
level of precision required by the control system. Typically it provides a resolution of
45   12 bits. The Analog to Digital Converter (411) provides the digitized sensor
information to the Microprocessor (401). This is done by means of connections (491),
which may be serial or parallel.

The Integrated Laser Communications Controller (320) in Figure 4 ensures that the laser is protected during power transients, ESD transients, over voltage or transients during power up. Laser protection starts with the use of a Power Control Interface (419). This contains a latch that disables the laser power when the system is
5   first energized during a power operation. The Power Control Interface (419) can be placed in a state that energizes the laser power by means of Control Lines (477) coming from the Microprocessor (401). Laser Power is enabled after any possible transients that occur during power up have died out. The Power Control Interface (419) controls the Laser Power Switch (420) by means of the Drive Signal (456). The
10   Laser Power Switch (420) contains Drive Transistors, which provide DC power to the laser through a pin at (457). For high power lasers external power transistors may be utilized in conjunction with the output at pin (457). The Power Supply Voltage (455) first enters an over voltage and Transient Protection Circuit (421), which ensures that the DC Power (455) utilized to power the laser will be free from damaging ESD
15   transients, and over voltage on the Power Supply Lines (455). The Power Control Interface (419) also utilizes data lines (492) to control a set of TEC Drivers (418). These drivers provide a multiplicity of power outputs (458,459,460,461), which are utilized to control turn on sequencing of power drivers used to run Thermo-Electric Coolers/Heaters (TEC). The TEC is used to maintain laser and other optical devices at
20   a constant temperature for critical applications such as Dense Wavelength Division Multiplexing.

Bias and Modulation Current Control of the lasers can be carried out by the utilization of D/A Converters or with Digital Potentiometers. Which of these devices are utilized is dependent on the configuration of the circuits in the Driver (301). If the
25   Driver (301) contains current mirrors that are set with a resistor of a given value, then the Digital Potentiometers (417) are utilized to control the currents in this case output (462) is connected to the driver in order to provide a resistance value utilized to control the magnitude of the modulation current. At the same time, the output pin (463) is also connected to the driver in order to provide a resistance value utilized to
30   control the magnitude of the Bias Current. The resistance in the Digital Potentiometers (462-463) is set by Control Lines (476) coming from the Microprocessor (401). If the Driver (301) contains current mirrors that can be set by controlling the current in a transistor such as in a voltage controlled current source configuration, then D/A converter outputs can be utilized to set the currents. In this
35   case, D/A Converters (416) are utilized to set the modulation in Bias Currents. Output (464) from D/A Converter (416) is a voltage output and will control the magnitude of the modulation current for the laser. Output (465) from the D/A Converter (416) is a voltage output and will control the magnitude of the Bias Current for the laser. Other outputs from the D/A Converters (416) control other system functions such as Laser
40   Wavelength Tuning Outputs (466,467). Alternatively D/A Converter (416) may contain additional multiple outputs, which can provide high resolution voltage outputs that can be utilized to tune the wavelength of multiple lasers such as for a Tunable VCSEL laser array. These outputs provide currents that are capable of driving semiconductor devices such as Bragg Gratings. Signal (470) is an output from the
45   D/A Converter (416), which provides a synthesized voltage to be used for calibration purposes by an Analog Laser Transmitter. The bank of D/A Converters (416) is controlled by Control Lines (475) being driven by the Microprocessor (401).

The Integrated Laser Communications Controller (320) contains features used to characterize laser communication links. In a typical laser communication link, a special drive signal is applied to the laser. The information is sent through the communications link, and is received at the destination of the link. The information is
5   then returned to our initial laser transmitter, sensed by means of an optical receiver channel and then returned to the Integrated Laser Communications Controller so that a determination can be made as to the value of critical parameters such as Channel Signal to Noise ratio, Bit Error Rate (BER), Wavelength or other parameters. Analog Characterization is facilitated by a signal at (433) provided by the Reference Data
10   Switch (426). The switch is controlled by the Microprocessor (401), which selects either Precision Reference (427) or a synthesized Signal (470). Control Signal (471) selects which input to the Reference Data Switch (426) connects to the Output (433). Digital Channel Characterization is accomplished by an output serial stream of data (434), generated by the Optical Link Characterization Circuits (425). These circuits
15   generate an appropriate stream of digital information used to determine parameters such as bit error rate (BER). The returning information from the opposite end of the communication channel is received at input 435. The Optical Link Characterization Circuits (425) are controlled with signal (426) being driven by the Microprocessor (401). In order to assist in switching between the test signal (435), the input signal
20   into the driver, and a returning signal from a remote transceiver, a Test System Switch (TSS) (428) is utilized. The switch is controlled by the Microprocessor (401) with control line (468). The TSS is capable of connecting a multiple of signals (431-432) to a multiple set of outputs (421-430). The Microprocessor (401) also provides a special signal (436) utilized to control other Link Characterization Switches.
25   The Integrated Laser Communications Controller (320) also contains a block of circuits for Internal Chip Diagnostics (422), which provide a test interface (454). These circuits are used to trouble shoot the hardware and may also provide a JTAG interface. Other circuits may include Wavelength Detector Hardware (423). This hardware interfaces with inputs signals (453) to other possible electro-optical devices
30   utilized to detect wavelength. The Wavelength Detector Hardware (423) communicates through interface (428) with the Microprocessor (401).
             The Controller (320) may contain programmable gain amplifiers (424) used to receive signals from a photodiode through input (451). Once the photodiode signal (479) is amplified, it is sent to the rest of the transceiver through output (452). The
35   programmable gain amplifier (424) is controlled by the Microprocessor (401) through the control line (479).

Methods Of Operation
       FIG 5 illustrates the methods of operation, comprising a real-time operating system.
40   FIG 5 is a diagram of the firmware imbedded in the Laser Communications Controller (320). The firmware contains the methods of operations for the Laser Communications Controller (320). There are methods of operations corresponding to the various blocks of circuits that need to be controlled in the various algorithms for executing control. Functionality of the firmware is orchestrated by a Transceiver
45   Real-Time Operating System (516). The Operating System (516) controls the execution of programs and routines, and forms an open driver interface for various user application programs. Among other functions of the Operating System (516) are parameter passing and configuration of the System (516). This allows for leveraging

of programs from one product generation to another, allows for connecting special programs from the user to the transceiver controls and allows utilization of built in facilities such as special drivers and utilities. The Operating System (516) is a Real Time Operating System in the sense that it responds to the requests of the various
5   Servo Systems in a prescribed period of time so that the control variables do not drift away from the desired set point.
       The hardware is controlled by Mixed Signal/Analog Device Drivers (501). These drivers control the various blocks analog and digital hardware such as D/A Converters, A/D Converter, Analog Multiplexer, Programmable Gain Amplifier and
10   Receiver Photodiode Gain Amplifier. Other built in programs are the Feedback Sensor Monitors (502). These routines acquire information from Temperature Sensor, Photodiodes, Laser Bias Current, Laser Modulation Current, Power Supply Voltage, Wavelength Locker/Sensor, and an Input Signal Duty Cycle Averager. Wavelength Division Multiplexing controls (503) is carried out by a Servo System, which insures
15   continuous real time adjustment of the Laser Wavelength. For this purpose the Servo System performs the necessary functions for calibrating the Wavelength at the factory, compensating for temperature changes and for device ageing. Power Device Drivers Control (504) is used to control the various hardware drivers utilized to control a Thermo-Electric Cooler used to maintain the laser temperature at a constant
20   value. Initialization (505) is run when the power of the transceiver is first turned on. It performs the initial load of factory calibration parameters, initialization of D/A Converters, and supportive system registers. Finally, once the Servo System utilized to control laser power is ready, the Initialization (505) turns on the Laser Power Switch Enable which connects the power supply to the laser when the system has
25   stabilized and there are no transients which could damage the laser. The Factory Calibration And Test (506) provides interfaces to test and measurement equipment and provides routines for calibrating the various control systems and devices in the Communications System at the end of the assembly line. The Digital Block Hardware Driver (507) controls the ROM, RAM, Digital General Purpose I/Os in the External
30   Memory Interface. System Utilities Driver (506) is provided by the Operating System to the various programs being executed. The Drivers consist of a Multiplier, Divider, Digital Filter, Digital Signal Processing, Real Time Timer Control and Interrupt Handlers.
       A critical program is the Laser Power Control System (515); this system insures that
35   the laser power is controlled in an accurate manner. The program contains Digital Servo Controls for the setting of the Laser Bias Current, Modulation Current, and Initial Manufacturing Variations of Parameters. Two types of Temperature Compensation are supported: the first is in-line compensation, which performs temperature laser adjustments without interrupting data transmission. The second type
40   of compensation uses the breaks in data transmission in order to compensate for the laser temperature effects. The Laser Power Control System (515) also contains routines to model the thermal transfer characteristics for the various pieces of hardware utilized in the laser transceiver. The Control System (515) also contains a Dynamic Thermal Effects Model for determining transient thermal behavior of the
45   laser depending on the characteristics of the signal to be transmitted. The Host I/O Communication (514) supports RS 232, Universal Serial Bus (USB) and Parallel Bus Communications with a Host Computer. The Optical Link Characterization (513) contains programs to support tests to determine the Bit Error Rate of the entire optical

communications link including the transmitter and a remote receiver. For this purpose the Optical Link Characterization (513) controls a Test System Switch (TSS), (428) found in the Integrated Laser Communications Controller (320). The TSS (428) is utilized to route the different signals in the transceiver in order to perform the

5   functions of the Optical Link Characterization. The program contains special routines to perform adjustments of parameters of the different electro-optical devices utilized in the communications transceiver. These adjustments can be performed remotely from a central control station or a node in the network. For this purpose, the remote control station examines parameters such as Wavelength and Polarization and sends

10   information back to the Integrated Laser Communication Controller (320) and instructs the controller (320) to perform any necessary adjustments. These adjustments are carried out in a closed loop control system to place communications transceiver in its optimal operating state. With the foregoing method, costly equipment is only required in one location of the network in an optical transmission

15   system, it minimized costly service calls and increases system reliability because the laser and other devices can perform within prescribed limits. The feature is particularly important Dense Wavelength Division Multiplexing Systems where the laser wavelength needs to be continuously maintained within narrow limits. In this case, the wavelength can be periodically adjusted from a remote location by a host

20   computer that is part of a system containing the necessary measuring instruments. The host computer returns instructions to the Integrated Laser Communications Controller. These instructions will adjust the appropriate hardware to tune the laser wavelength. Other possible programs that can be connected to the operating system are an interface for Indirect Drive Electro-Optic Modulator Controls (510) and a

25   MEMS Optical Switch Control (509). The embedded firmware contains a full set of Hardware Diagnostics Controls (511).
       A key set of programs consists of Predicted Performance and Ageing Compensation (512). These programs contain aging compensation for Laser Bias Current, Laser Modulation Current and Photodiode Characteristic. Predicted performance is capable

30   of analyzing with the use of feedback elements various characterizes of the laser. For example: linearity, discontinuities and other parameters. Another feature includes the measurements of system noise. This is required in order to set the Laser Bias Threshold to the appropriate value so that the laser does not turn off with a logic zero. This will cause the laser to fall into the spontaneous emission region, which would

35   slow the laser response for switching to logic one. Other programs can include Adaptive Threshold Bias and Adaptive Modulation of the laser. These programs allow for compensation of the drive as the laser experiences changes due to aging and temperature changes. For this purpose the Bias and Modulation Drives are set to a value that satisfies the optical transmission requirements but without over driving the

40   laser. When the laser characteristic is determined to change due to aging or temperature, the Bias and Modulation Drives are adjusted accordingly in order to satisfy the optical transmission requirements. This approach extends the life of the laser.

45   A summary follows of the apparatus and methods of operation and unique features of the present invention.
       1. An Integrated Laser Communications Controller.
       2. A controller as in item 1 implemented in a single integrated circuit

3. A Controller as in number 2 containing several or all of the following
elements:

a microprocessor(401),
ROM (402),
RAM (403),
non volatile RAM (404),
External storage interface (437),
Reset Generator (405),
Clock Generator (406),
Timers (407),
Digital I/Os (408),
Serial I/Os (409),
Parallel I/Os (410),
High performance operational amplifiers (415),
Sample Hold Amplifiers (414),
Analog Multiplexer (413),
Programmable Gain Amplifier (413a),
Analog to Digital Converter (411),
Monitoring Photodiode Current Amplifiers (424),
Digital to Analog Converters (416),
Digital Potentiometers (417),
Laser Power Control Interface (419),
Laser Power Switch (420),
Thermoelectric cooler drivers (418),
Laser Over voltage and transient Protection (421),
Precision Voltage Reference (427),
Reference Drive Switch (426),
Optical Link Characterization Circuits (425),
Signal detector circuits (493),
Wavelength detector support (423),
Internal Chip diagnostics (422), and
Receiver channel programmable gain amplifiers (424)

4. Other types of logic or mixed signal elements as in 3 used to control an
Optical transceiver for fiber optics or space/air light wave communications.

5. A Controller as in 3 where the controller Integrated circuit may also include
the Laser Driver for a single IC system.

6. A Controller as in 3 where the controller Integrated circuit contains D/A
converters, which can have high current outputs to directly, drive laser bias
currents.

7. A controller as in 5, where in addition to the driver, the controller may
undergo special manufacturing processes to include one or more VCSEL
lasers on the same Integrated Circuit.

8. A method of operation with an embedded real-time operating system, which
orchestrates program execution.

9. A method of operation as in 8 with a Digital Servo Control system for Power
Control

10. A method of operation as in 8 for Wavelength control.

11. A set of predictive performance algorithms, part of operating system in item 8 for laser with temperature and aging.

12. A set of predictive performance algorithms part of operating system in item 8 which dynamically adjust the bias and modulation drives reaching an adequate compromise to extend life and optimize signal to noise ratio.

13. A set of embedded hardware and firmware part of operating system in item 8 to determine Bit Error Rate and other laser parameters.

14. A program part of operating system in item 8 to allow remote central station calibration of wavelength with a remote computer and remote test and measurement equipment which sensing at the remote site of the laser signal and returns to the laser controller information used to close the loop and tune the wavelength.

What is claimed is:

5.
An integrated laser communications control system (200) comprising:

a modulation drive signal (300),
a driver (301),
a digital laser controller IC (320),
a set of sensors (306,307,309,319), and
10   a Laser Module (303),
wherein control methods control the various operational parameters of the Laser
Module (303), wherein the control first starts with a modulation drive signal (300)
causing the driver (301) to send an appropriate signal to an output (302) so that a laser
can send an optical power output (304) proportional to a modulation drive signal
15   (300), and further wherein the control methods embedded in a digital laser controller
IC (320) consist of control algorithms embedded in firmware.

2.   An integrated laser communications control system (200) of claim 1, wherein
the digital laser controller is implemented in a single Integrated Circuit IC (320)
20   preferably comprises digital functions of
a microprocessor(401),
ROM (402),
RAM (403),
non volatile RAM (404),
25   External storage interface (437),
Reset Generator (405),
Clock Generator (406),
Timers (407),
Digital I/Os (408),
30   Serial I/Os (409),
Parallel I/Os (410),
High performance operational amplifiers (415),
Sample Hold Amplifiers (414),
Analog Multiplexer (413),
35   Programmable Gain Amplifier (413a),
Analog to Digital Converter (411),
Monitoring Photodiode Current Amplifiers (424),
Digital to Analog Converters (416),
Digital Potentiometers (417),
40   Laser Power Control Interface (419),
Laser Power Switch (420),
Thermoelectric cooler drivers (418),
Laser Over voltage and transient Protection (421),
Precision Voltage Reference (427),
45   Reference Drive Switch (426),
Optical Link Characterization Circuits (425),
Signal detector circuits (493),
Wavelength detector support (423),
Internal Chip diagnostics (422), and

Receiver channel programmable gain amplifiers (424), wherein these support circuits control a laser.

5   3.   In firmware of an integrated laser communications controller (320), a method of operation comprising the steps of:

receiving a modulation drive signal (300), and
10   orchestrating control of the firmware in a transceiver real time operating
system (516), wherein the real time operating system (516) further comprises
the steps of:
controlling the execution of programs and routines,
forming an open drive interface for various user application programs,
configuring of the operating system (516) ,
15   passing parameters,
connecting special programs from the user to the transceiver controls, and
utilizing drivers and utilities, wherein the operating system is further
responding to requests of servo systems in a prescribed period of time so that control
variables do not drift away from a desired set point.
20

4.   In firmware of an integrated laser communications controller (320), wherein
- the controlling step of the method of operation of claim 3 further comprises the steps
of:
25

Controlling the laser power accurately(515),
setting parameters (515),
adjusting laser temperature (515),
compensating for laser temperature effects (515), and
30   determining transient thermal behavior (515).

5.   In firmware of an integrated laser communications controller (320), wherein
the forming step of the method of operation of claim 3 further comprises the steps of:
35

interfacing with test and measurement equipment (506),
providing routines for calibrating control systems and devices (506),
controlling the ROM (402), RAM (403), and digital I/Os (408) (507),
determining the bit error rate of the entire optical communications link (513),
40   controlling a Test System Switch (428) for routing signals in the transceiver,
adjusting of parameters of different electro-optical devices, wherein the
transceiver is placed in its optimal operating state, thereby increasing system
reliability, minimizing costly service calls, and minimizing costly equipment.

45   6.   In firmware of an integrated laser communications controller (320), wherein
the determining the bit error rate of the entire optical communications link (513) step
of the method of operation of claim 5, further comprises the steps of:
examining parameters such as Wavelength and Polarization,
sending information back to the Integrated Laser Communication Controller
50   (320), and

instructing the controller (320) to perform any necessary adjustments, wherein these adjustments are carried out in a closed loop control system to place a communications transceiver in its optimal operating state, and further wherein these adjustments can be performed remotely from a central control station or, alternatively, a
5   node in the network.

7.   In firmware of an integrated laser communications controller (320), wherein the configuring step of the method of operation of claim 3 further comprises the steps of:
        initializing the operating system (516),
10   loading of factory calibration parameters (505), and
        turning on the Laser Power Switch Enable (505).

8.   In firmware of an integrated laser communications controller (320), wherein the passing parameters step of the method of operation of claim 3 further comprises the steps
15   of:

        Controlling analog and digital hardware (501),
        acquiring information from sensors (502),
        adjustment of laser wavelength in real time (503),
20   maintaining the laser temperature at a constant value (504), and
        compensating for aging of laser bias current, laser modulation current, and
        Photodiode characteristic (512).

9.   In firmware of an integrated laser communications controller (320), wherein the
25   connecting special programs from the user to the transceiver controls step of the method of operation of claim 3 further comprises the step of:

        Supporting host I/O communications and buses (514).

30   10.   In firmware of an integrated laser communications controller (320), wherein the utilizing drivers and utilities step of the method of operation of claim 3 further comprises the step of:

        Interfacing with system utilities drivers (508), modulator controls (510), optical
35   switch control (509), and diagnostic controls (511).

Figure 1.
Prior Art. Analog Controller
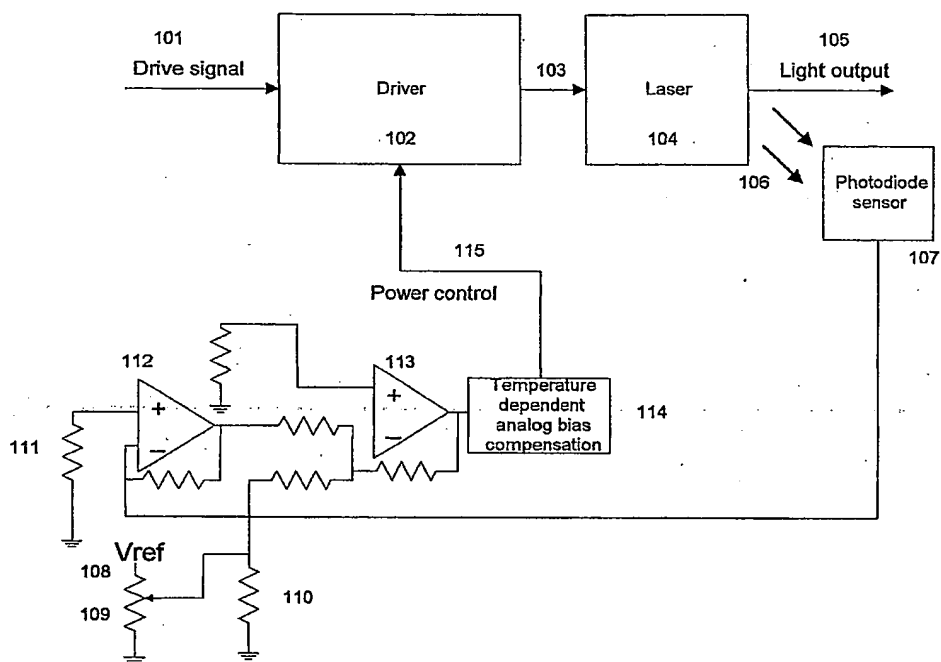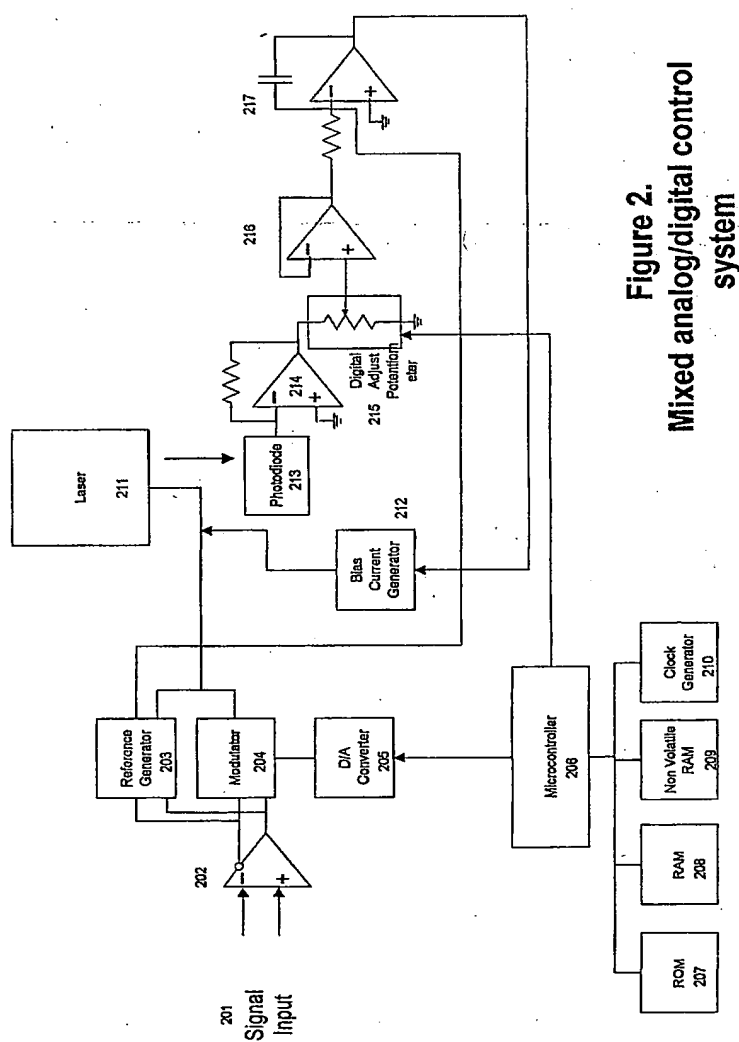
Figure 2.
Mixed analog/digital control
system

Figure 3.
Integrated Laser
Communications Control
System

<u>200</u>

Fig 4. Integrated Laser
Communications Controller

Figure 5: Embedded Firmware

Host I/O Communications
*RS232
*USB
*Parallel
514

Optical Link Characterization
*Bit Error Rate Harware Control
*Test System Switch Control
*Remote Central Station Parameter Adjustments
*Remote Wavelength Calibration
513

Predictive Performance and Aging Compensation
*Bias setting Aging
*Modulation Setting Aging
*Photodiode Aging
*Characteristic Curve Linearity
*Discontinuity in Characteristic
*Other Parameters
*Adaptive Bias and Modulation (Change as aging and temperature change requiremens to extend life)
*Noise Measurement
512

Hardware Diagnostics Controls
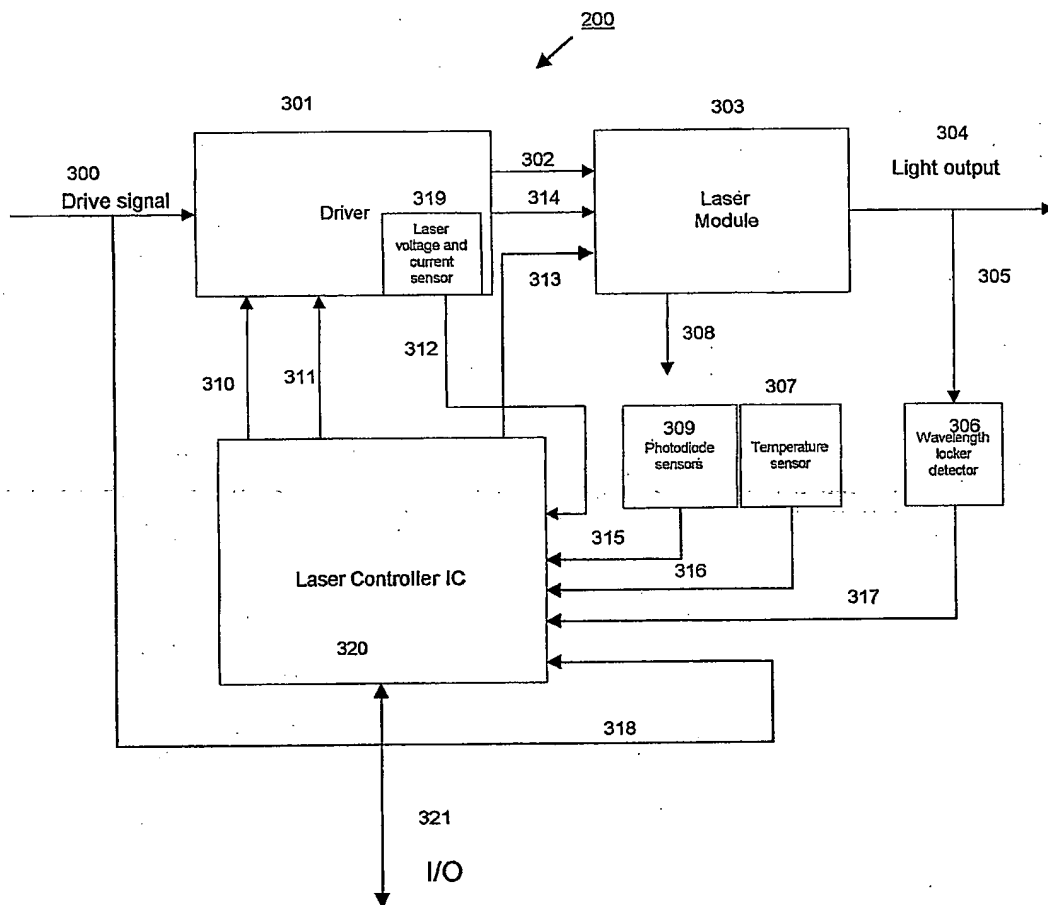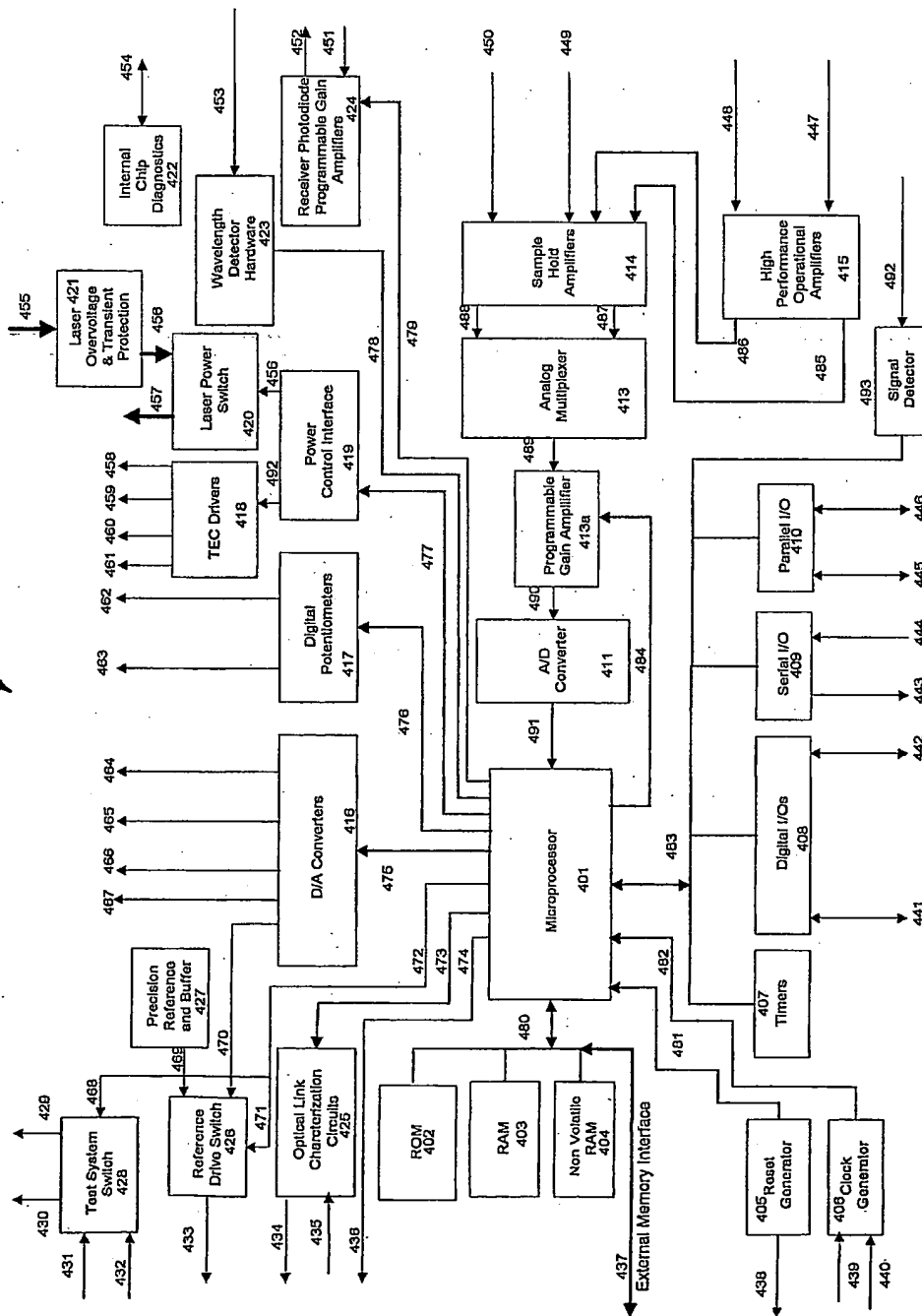511

Indirect Drive Electro Optic Modulator Controls Interface
510

MEMS Optical Switch Control
509

System Utilities Drivers
*Multiplier
*Divider
*Digital Filter, Digital Signal Processing
*Real Time Timers
*Interupts
508

Laser Power Control System
*Digital Servo Controls
*Bias setting
*Modulation Setting
*Initial Manufacturing Variations and Parameters
*Temperature Compensation
  *In Line, without service interrupt
  *Using data transmission breaks
  *Thermal Models for Hardware Configurations, Thermal Resistance
*Dynamic Thermal Effects
515

Transceiver Real Time Operating system
*Program / Routine Execution Controls
*System Configurations
*Open Driver Interface for User Applications
*Parameter Passing
*Utilities Controls
516

Digital Block Hardware Driver
*ROM
*RAM
*Digital General Purpose I/Os
*External storage Interface
506

507

Mixed Signal/Analog Device Drivers
*D/A Converters
*A/D Converter
*Analog Multiplexer
*Programmable Gain Amplifier
501

Feedback Sensor Monitors
*Temperature
*Photodiodes
*Laser Bias Current
*Laser Modulation Current
*Power Supply Voltage
*Wavelength Locker/Sensor
*Input Signal Duty Cycle Averager
502

Wavelength Division Multiplexing Control System
*Tunable Laser Control
*Wavelength Factory Calibration
*Temperature Compensation
*Device Aging Compensation
503

Power Device Drivers Control
*TEC Controls
504

Initialization
*Load Factory Calibration Parameters
*Initialization for D/A Converters
*Laser Power Switch Enable
505

Factory Calibration and Test
*Instrument Interface
*Calibration Routines